Greinargerð
04008

Hörður Þór Sigurðsson

Results of the 2D avalanche model SAMOS for Ólafsvík and Ólafsfjörður

VÍ-VS-07
Reykjavík
Apríl 2004

Contents

Background

The 2D avalanche model SAMOS, developed by the Advanced Simulation Technologies (AVL) of Graz, Austria, has been run for several starting zones in the mountains above the villages of Ólafsvík and Ólafsfjörður in Iceland. The runs are intended to shed light on the following aspects of the avalanche hazard situation in the villages:

1. The shortening of avalanche run-out due to lateral spreading.
2. The difference in run-out between avalanches from the main gullies due to the different sizes of the starting zones and different degree of lateral spreading.
3. The direction of the main avalanche tongues from the gullies.
4. The shape of the main avalanche tongues from the gullies.

The results of the runs will be used in the delineation of the hazard zones for the villages. Similar results have previously been used for the same purpose for the villages Eskifjörður, Neskaupstaður, Seyðisfjörður, Siglufjörður, Ísafjörður and Hnífsdalur, Bolungarvík, Bíldudalur and Patreksfjörður (Jóhannesson *et al.*, 2001a,b, 2002a,b,c, 2003).

The SAMOS model was developed for the Austrian Avalanche and Torrent Research Institute in Innsbruck by AVL and has recently been taken into operational use in some district offices of the Austrian Foresttechnical Service in Avalanche and Torrent Control. The model is based on assumptions regarding avalanche dynamics similar to other depth integrated 2D avalanche models that are used in Switzerland and France. Friction in the dense flow part of the model is assumed to be composed of a Coulomb friction term proportional to a coefficient $\mu = \tan(\delta)$ with $\delta = 16.0^\circ$($\mu = 0.287$) and a turbulent friction term which may be represented by a coefficient $\xi = 446$ m^2/s (Sampl and Zwinger, 1999). Rather than adding the two friction components as is done in the Swiss and French 2D models, the SAMOS model uses the maximum of the two friction terms and ignores the smaller term. This leads to slightly higher modelled velocities than for the Swiss and French 2D models for avalanches with similar run-out. The velocities are, also, somewhat higher than corresponding velocities in the same path from the Swiss AVAL-1D model or the PCM model (Sauermoser, personal communication). The model runs are, furthermore, based on an assumed value $\rho = 200$ kg/m^3 for the density of flowing snow. The density is used to convert a given mass of snow in the starting zone to a corresponding volume or depth perpendicular to the terrain of the snow that is released at the start of the simulation.

A description of the applicability of the SAMOS model for Icelandic conditions can be found in the above mentioned reports about SAMOS model runs for other Icelandic villages.

Results for Ólafsvík

A total of 6 different avalanche starting zones were defined in the mountains and hills above the settlement in Ólafsvík, 1 in Tvísteinahlíð (labeled 1) and 5 in Ennishlíð in the Enni mountain (labeled 2-6). Starting zones 2, 3 and 4 are believed to accumulate less snow than the other starting zones.

The starting zone classification system below is the same as the one previously used in the other villages where SAMOS similations have been carried out. Only classes I and III were used for the Ólafsvík runs.

Class	Relative snowdepth	Comment
I+	2	Deep and narrow gullies near the top of the mountain
I	1	Large deep bowls or gullies near the top of the mountain
II	2/3	Shallow bowls or relatively flat areas near the top of the mountain
III	1/2	Small and shallow bowls at comparatively low elevations
IV	1/4	Other parts of the mountain with a small snow accumulation potential

Four runs with the SAMOS model were made in Ólafsvík. The first and third run were started with a uniform snow depth of 1.25 m in class I starting areas and the other runs were started with a snow depth of 2.5 m in class I starting areas. The snow depth in all the runs was determined from the relative snow depth class for the respective areas as given in the table above.

The following table gives the total mass and volume of snow for each of the runs.

Input	run1	run2	run3	run4
Snow depth in class I areas (m)	1.25	2.5	1.25	2.5
Total mass (10^3t)	4.92	9.84	3.28	6.56
Total volume ($10^3 m^3$, $\rho = 200$ kg/m^3)	24.6	49.2	16.4	32.8

The mass and volume are total values for all the avalanches that were released simultaneously in the different starting zones. The snow was released simultaneously from the multiple starting zones in each run in order to simplify the model computations and in order to make them more economical in terms of computer time and time needed to set up the runs. This aspect of the simulations should not be taken to indicate that simultaneous release of this kind is likely to occur in Nature.

The following table summarises the area and the relative snow depth for each of the starting zones in Ólafsvík. The last column of the table lists the runs where snow was released from the zone.

Starting zone		Map area	Area	Relative	runs
id	name	(10^3m^2)	(10^3m^2)	snow depth	
1	Tvísteinahlíð	12.4	15.1	1	1,2
2	Ennishlíð above the street Engihlíð	4.6	5.9	1/2	3,4
3	Ennishlíð above the street Engihlíð	4.5	5.8	1/2	3,4
4	Ennishlíð above the street Engihlíð	4.1	5.8	1/2	3,4
5	Ennishlíð above the street Ennisbraut	3.4	4.6	1	1,2
6	Ennishlíð above the street Ennisbraut	3.5	4.5	1	3,4
Total		32.5	41.7	—	—

As in the simulations described in separate reports for the other villages where SAMOS simulations have been carried out, snow entrained in the lower part of the path is not considered in the computations. Therefore, the volume of the avalanches from each starting zone is smaller than for real, large avalanches that might be released from the corresponding part of the mountain.

The results of the 4 runs are displayed as coloured contour plots of the depth and velocity of the flowing avalanche at 10 second intervals (files `ov_run1-4.ppt` on the attached CD). The CD also contains similar files for other Icelandic villages where SAMOS computations have been carried out. Plots of the maximum dynamic pressure (given by $p = \rho u^2$) along the paths were also made (also on the CD). Some of the results are shown on Figs. 2-9 (the flow depths are in m and the maximum pressure in kPa on the figures).

Starting zone		Volume (10^3m^3)		Run-out index	
id	name	run1/3	run2/4	run1/3	run2/4
1	Tvísteinahlíð	18.9	37.7	15.1	15.6
2	Ennishlíð above the street Engihlíð	3.7	7.3	10.8	12.8
3	Ennishlíð above the street Engihlíð	3.6	7.3	10.0[a]	10.2[a]
4	Ennishlíð above the street Engihlíð	3.6	7.3	12.3	13.2
5	Ennishlíð above the street Ennisbraut	5.8	11.5	12.9	13.8
6	Ennishlíð above the street Ennisbraut	5.6	11.3	13.5	14.1
Total		41.2	82.4	—	—

[a]The avalanche terminates on the shelf at about 100 m a.s.l.

The release volume (ρ = 200 kg/m^3) and run-out index (Jónasson and others, 1999) for the avalanches from the different starting zones for each of the 4 Ólafsvík simulations is summarised in the table above. The columns labeled “run1/3” summarise the results of runs 1 and 3 and the columns labeled “run2/4” summarise the results of runs 2 and 4. The columns labeled “run1/3” correspond to a snow depth of 1.25 m in class I starting zones and columns labeled “run2/4” correspond to a snow depth of 2.5 m in class I starting zones.

It should be noted that the volumes given in the table are not completely consistent with the volumes given in the previous table that summarises the mass and volume of snow in each run. This discrepancy, which is in all cases is around 1%, is caused by discretisation errors in the computational grid because the delineation of the starting zones does not run along grid boundaries.

Previous simulations for other villages in Iceland (Jóhannesson and others, 2001a,b, 2002 a,b,c, 2003) showed that large bowl shaped class I starting zones, for example in Neskaupstaður, release avalanches that reach a run-out index in the approximate range 15.5–16.5 for a snow depth of 1.25 m and run-out index in the range 17–18 for a snow depth of 2.5 m. The much smaller class I starting zones in Bolungarvík produced shorter avalanches that reached run-out index 13.5–14 and 15–15.5 for snow depths of 1.25 and 2.5 m, respectively. The class II and III starting zones in Neskaupstaður produced avalanches with a run-out similar as the class I zones in Bolungarvík in some cases, whereas other starting zones, for example in Urðarbotn, released avalanches with an intermediate run-out index of about 15 for runs with a class I snow depth of 1.25 m.

The run-out of the simulated avalanches in Ólafsvík is not comparable to other villages in Iceland where the simulation has been carried out because of the very low hills and small starting zones. The starting zone in Tvísteinahlíð is only at about 90 m a.s.l. and the size of each of the starting zone in Ennishlíð is only about 5–6 $10^3 m^2$.

The avalanches from Tvísteinahlíð reach run-out index about 15 and 15.5 for the small and large SAMOS runs, respectively.

Apart from Tvísteinahlíð, the longest run-out obtained in the Ólafsvík simulations is in Ennishlíð above the street Ennisbraut where the avalanches reach 13–13.5 and 14 for the small and large SAMOS runs, respectively.

In Ennishlíð above the street Engihlíð the modelled avalanches are a bit shorter, *i.e.* in the approximate range 11–12 for the small SAMOS runs and about 13 for large SAMOS runs. The avalanche from starting zone 3 terminates on the shelf at about 100 m a.s.l. and therefore the run-out is shorter from that area.

The simulations in Tvísteinahlíð reach into the settlement and the simulations in Ennishlíð above the street Ennisbraut reach the industrial area and beyond the shoreline.

Results for Ólafsfjörður

A total of 10 different avalanche starting zones were defined in the Tindaöxl mountain above the inhabited area of Ólafsfjörður (labeled 1-10) and 8 starting zones were defined in Ósbrekkufjall mountain to the west of the settlement (labeled 11-18).

The same starting zone classification system was used as described above in the section about the Ólafsvík simulations.

Six runs with the SAMOS model were made in Ólafsfjörður, four in the Tindaöxl mountain and two in the Ósbrekkufjall mountain. The first, third and fifth run were started with a uniform snow depth of 1.25 m in class I starting areas and the other runs were started with a snow depth of 2.5 m in class I starting areas. The snow depth in all the runs was determined from the relative snow depth class for the respective areas as given in the snow depth classification table in the previous section.

The following table gives the total mass and volume of snow for each of the runs.

Input	run1	run2	run3	run4	run5	run6
Snow depth in class I areas (m)	1.25	2.5	1.25	2.5	1.25	2.5
Total mass (10^3t)	24.4	48.7	24.9	49.7	297.2	594.4
Total volume (10^3m^3, ρ = 200 kg/m^3)	122.0	243.5	124.5	248.5	1486.0	2972.0

The mass and volume are total values for all the avalanches that were released simultaneously in the different starting zones. The snow was released simultaneously from the multiple starting zones in each run in order to simplify the model computations and in order to make them more economical in terms of computer time and time needed to set up the runs. This aspect of the simulations should not be taken to indicate that simultaneous release of this kind is likely to occur in Nature.

The following table summarises the area and the relative snow depth for each of the starting zones in Ólafsfjörður. The last column of the table lists the runs where snow was released from the zone.

Starting zone id	name	Map area (10^3m^2)	Area (10^3m^2)	Relative snow depth	Runs
1	Tindaöxl	6.1	8.2	1/2	1,2
2	Tindaöxl	5.9	8.2	1/2	3,4
3	Tindaöxl	5.6	7.7	1/2	1,2
4	Tindaöxl	24.5	30.2	1/2	3,4
5	Tindaöxl	33.3	41.5	1/2	1,2
6	Tindaöxl	54.8	67.4	1/2	3,4
7	Tindaöxl	30.2	37.3	1/2	1,2
8	Tindaöxl	48.1	59.1	1/2	3,4
9	Tindaöxl	28.1	33.8	1/2	3,4
10	Tindaöxl	81.1	99.4	1/2	1,2
11	Ósbrekkufjall	207.3	253.3	1	5,6
12	Ósbrekkufjall	139.8	167.0	1	5,6
13	Ósbrekkufjall	153.0	183.8	1	5,6
14	Ósbrekkufjall	116.3	140.0	1	5,6
15	Ósbrekkufjall	105.3	125.0	1	5,6
16	Ósbrekkufjall	100.6	119.9	1	5,6
17	Ósbrekkufjall	114.1	135.5	1	5,6
18	Ósbrekkufjall	51.7	62.4	1	5,6
Total		1306.1	1579.7	—	—

As described in the previous section about Ólafsvík, snow entrained in the lower part of the path is not considered in the computations. Therefore, the volume of the avalanches from each starting zone is smaller than for real, large avalanches that might be released from the corresponding part of the mountain.

The results of the 6 runs are displayed as coloured contour plots of the depth and velocity of the flowing avalanche at 10 second intervals (files `oj_run1-4.ppt` and `of_run5-6.ppt` on the attached CD). The CD also contains similar files for other Icelandic villages where SAMOS computations have been carried out. Plots of the maximum dynamic pressure (given by $p = \rho u^2$) along the paths were also made (also on the CD). Some of the results are shown on Figs. 11-22 (the flow depths are in m and the maximum pressure in kPa on the figures).

Starting zone		Volume (10^3m^3)		Run-out index	
id	name	run1/3/5	run2/4/6	run1/3/5	run2/4/6
1	Tindaöxl	5.1	10.2	12.8	13.6
2	Tindaöxl	5.1	10.2	12.7	13.5
3	Tindaöxl	4.8	9.6	12.5	13.3
4	Tindaöxl	18.9	37.8	12.6	13.4
5	Tindaöxl	25.9	51.8	14.0	14.8
6	Tindaöxl	42.1	84.2	14.6	15.6
7	Tindaöxl	23.3	46.6	14.1	14.9
8	Tindaöxl	36.9	73.8	14.5	15.3
9	Tindaöxl	21.1	42.2	13.9	14.8
10	Tindaöxl	62.1	124.2	14.7	15.2
11	Ósbrekkufjall	316.6	633.2	≈19.0	—
12	Ósbrekkufjall	208.8	417.6	17.4	17.8
13	Ósbrekkufjall	229.8	459.6	16.6	17.0
14	Ósbrekkufjall	175.0	350.0	≈16.0[a]	≈17.5[a]
15	Ósbrekkufjall	156.3	312.6	≈17.0[a]	≈18.5[a]
16	Ósbrekkufjall	149.9	299.8	≈16.5[a]	≈17.0[a]
17	Ósbrekkufjall	169.4	338.8	≈17.0[a]	≈18.5[a]
18	Ósbrekkufjall	78.0	156.0	15.6	17.2
Total		1729.1	3458.2	—	—

[a]Run-out index approximated due to interaction with flow from neighbouring starting zone.

The release volume (ρ = 200 kg/m^3) and run-out index (Jónasson and others, 1999) for the avalanches from the different starting zones in the mountain for each of the 6 Ólafsfjörður simulations is summarised in the table above. The "run1/3/5" column corresponds to a class I snow depth of 1.25 m and the "run2/4/6" column corresponds to a snow depth of 2.5 m in class I starting zones.

The avalanches from starting zone 11 reach the slope on the other side of the valley. Therefore the run-out index is not given for the large SAMOS run.

The run-out index is approximated for starting zones 14–17 because the simulated avalanches in that area interact with each other.

As noted in the section about Ólafsvík, the volumes given in the table are not completely consistent with the volumes given in the previous table that summarises the mass and volume of snow in each run due to small discretisation errors in the computational grid.

The simulated run-out at Ósbrekkufjall is comparable to the modelled run-out from large bowl shaped class I starting areas in some of the other communities where SAMOS simulations have been carried out, for example in Neskaupstaður (Jóhannesson and others, 2001a). The starting zones are very large and the upper part of the path is concave that leads to converging flow and reduces the spreading and the thinning of the flow in the run-out area. The avalanches from Ósbrekkufjall reach run-out index 16-17 and 17–18.5 for the small and large SAMOS runs, respectively and reach the sea for both runs below some of the starting zones. The run-out below starting zones 14–17 may be overestimated due to interaction of avalanches between the gullies. The danger of avalanches from the starting zones in Ósbrekkufjall is already a well known fact.

The run-out of the simulated avalanches from the (class III) starting areas in Tindaöxl is about 12.5 and 13.5 for the small and large SAMOS runs, respectively, from the smaller starting zones (1–4). Avalanches from other starting zones in Tindaöxl (5–10) reach run-out of about 14 and 15 for the small and large SAMOS runs, respectively. Avalanches from starting zone 6 have the longest run-out in Tindaöxl, namely 14.6 for the small run and 15.6 for the large run which reach the shoreline.

Some of the simulations in Tindaöxl reach into the upper part of the settlement and the avalanche from starting zone 6 reaches beyond the shoreline. The avalanches from Ósbrekkufjall do not threaten the main settlement in Ólafsfjörður.

References

Jóhannesson, T., Þ. Arnalds and L. Tracy. 2001a. *Results of the 2D avalanche model SAMOS for Bolungarvík and Neskaupstaður.* Reykjavík, Icel. Met. Office, Rep. 01011.

Jóhannesson, T., Þ. Arnalds and L. Tracy. 2001b. *Results of the 2D avalanche model SAMOS for Siglufjörður.* Reykjavík, Icel. Met. Office, Rep. 01019.

Jóhannesson, T., Þ. Arnalds and L. Tracy. 2002a. *Results of the 2D avalanche model SAMOS for Seyðisfjörður.* Reykjavík, Icel. Met. Office, Rep. 02008.

Jóhannesson, T., Þ. Arnalds and L. Tracy. 2002b. *Results of the 2D avalanche model SAMOS for Eskifjörður.* Reykjavík, Icel. Met. Office, Rep. 02013.

Jóhannesson, T., Þ. Arnalds and L. Tracy. 2002c. *Results of the 2D avalanche model SAMOS for Ísafjörður and Hnífsdalur.* Reykjavík, Icel. Met. Office, Rep. 02018.

Jóhannesson and L. Tracy. 2003. *Results of the 2D avalanche model SAMOS for Bíldudalur and Patreksfjörður.* Reykjavík, Icel. Met. Office, Rep. 03012.

Jónasson, K., S.Þ. Sigurðsson and Þ. Arnalds. 1999. *Estimation of avalanche risk.* Reykjavík, Icel. Met. Office, Rep. R99001.

Zwinger, T., A. Kluwick and P. Sampl. 2003. Simulation of dry-snow avalanche flow over natural terrain. *In* Hutter, K. and N. Kirchner, *ed. Dynamic Response of Granular and Porous Materials under Large and Catastrophic Deformations, Lecture Notes in Applied and Computational Mechanics.* Springer, Heidelberg, **11**, 161–194.

Figures

Figure 1. Location map for Ólafsvík.

Figure 2. Simulated final snow depth for run 1 in Ólafsvík.

Figure 3. Simulated final snow depth for run 2 in Ólafsvík.

Figure 4. Simulated final snow depth for run 3 in Ólafsvík.

Figure 5. Simulated final snow depth for run 4 in Ólafsvík.

Figure 6. Simulated maximum dynamical pressure for run 1 in Ólafsvík.

Figure 7. Simulated maximum dynamical pressure for run 2 in Ólafsvík.

Figure 8. Simulated maximum dynamical pressure for run 3 in Ólafsvík.

Figure 9. Simulated maximum dynamical pressure for run 4 in Ólafsvík.

Figure 10. Location map for Ólafsfjörður.

Figure 11. Simulated final snow depth for run 1 in Ólafsfjörður, Tindaöxl.

Figure 12. Simulated final snow depth for run 2 in Ólafsfjörður, Tindaöxl.

Figure 13. Simulated final snow depth for run 3 in Ólafsfjörður, Tindaöxl.

Figure 14. Simulated final snow depth for run 4 in Ólafsfjörður, Tindaöxl.

Figure 15. Simulated maximum dynamical pressure for run 1 in Ólafsfjörður, Tindaöxl.

Figure 16. Simulated maximum dynamical pressure for run 2 in Ólafsfjörður, Tindaöxl.

Figure 17. Simulated maximum dynamical pressure for run 3 in Ólafsfjörður, Tindaöxl.

Figure 18. Simulated maximum dynamical pressure for run 4 in Ólafsfjörður, Tindaöxl.

Figure 19. Simulated final snow depth for run 5 in Ólafsfjörður, Ósbrekkufjall.

Figure 20. Simulated final snow depth for run 6 in Ólafsfjörður, Ósbrekkufjall.

Figure 21. Simulated maximum dynamical pressure for run 5 in Ólafsfjörður, Ósbrekkufjall.

Figure 22. Simulated maximum dynamical pressure for run 6 in Ólafsfjörður, Ósbrekkufjall.